# Cognitive Performance Dynamics: MMSE Analysis by Group, Gender, and Visit Frequency

Technical Assignment 4

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**Link to .ipynb code file:**
https://colab.research.google.com/drive/1BN0AXSxfIc29HKkCgIuP7oezWl0z6qIW?usp=sharing

## 1. Introduction

This research explores the impact of various factors on cognitive performance, specifically focusing on the Mini-Mental State Examination (MMSE) scores. The dataset includes information on subjects' demographics, group classification (e.g., Demented, Non-demented, Converted), and MMSE among other scores across different visits. The analysis aims to answer research questions regarding the effects of group classification and gender on MMSE scores across visits.

## 2. Research Questions

The research questions addressed in this analysis are as follows:

- Does the 'Group' variable (e.g., Nondemented vs. Demented) have a significant effect on cognitive performance (MMSE) across different visits?
- Is there a significant difference in cognitive performance (MMSE) between males and females across different visits?

## 3. Exploratory Data Analysis (EDA)

In any statistical analysis, a crucial first step is to thoroughly explore the dataset to gain insights into its structure, distribution, and potential patterns. In this analysis, both non-graphical and graphical exploratory analysis was conducted to understand the dataset's characteristics fully.

The first statistics computed was the count of subjects in each group (demented, non-demented, and converted) as shown in table 3.1, however, it should be noted that the count is doubled as each subject occurs twice in the dataset as they are visit the center twice. This was further assessed through a barplot visual, figure 3.2, to see the distribution of across the three groups. Both analyses relay that the non-demented group has the highest subjects assigned among the three groups, and the converted group has the least. Figure 3.3 further slices the analysis to see the distribution of observations in the three groups across both visits.

Furthermore, the distribution of genders was also analysed through the barplot in figure 3.4, which displays female subjects to be the dominant gender in the research study. Figure 3.5 further slices the analysis to see the distribution of the genders in the three groups. Females appear to be the common in the non-demented and converted groups, while males have a greater occurrence frequency in demented group.

In addition, non-graphical EDA was conducted on the groups' and genders' MMSE scores, as shown in tables 3.6 and 3.7. The converted group shows a decrease in the mean MMSE score from the first visit to the second visit. The demented group has the lowest average MMSE scores overall, with a slight decrease in the second visit. The non-demented group shows minimal change in the mean scores between the two visits. The second table, table 3.6, displays both genders to be showing a decrease in the mean scores from the first and second visit, with females having higher mean scores overall. However, females have higher standard deviations compared to males in both visits indicating more variability in their scores.

| Group | Count | Actual Count |
|---|---|---|
| Non-Demented | 142 | 71 |
| Demented | 126 | 63 |
| Converted | 26 | 13 |

*Table 3.1 - Count of Subjects in each Group*

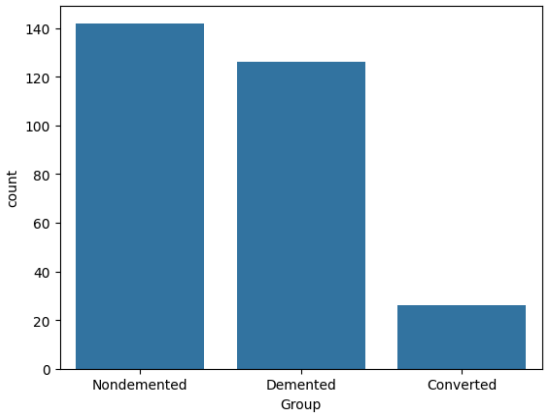


*Figure 3.2 - Bar Plot of the Three Groups*

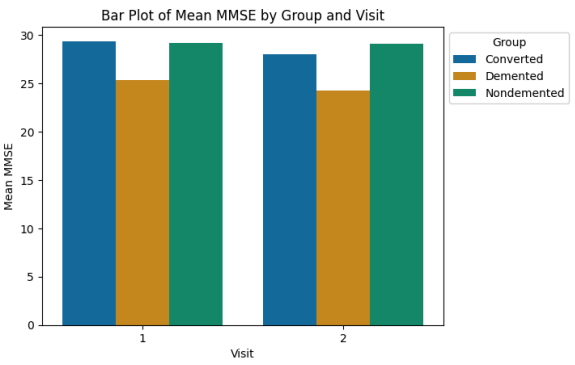


*Figure 3.3 - Barplot of MMSE scores by Group and VIsit*

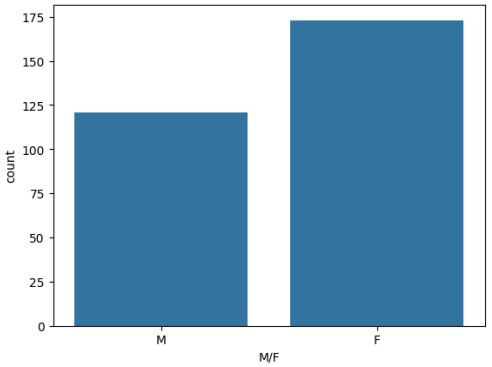


*Figure 3.4 - Barplot of Gender Frequency*

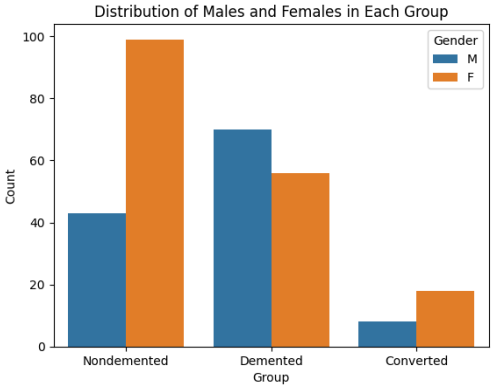


*Figure 3.5 - Distribution of Males and Females in Each Group*

| Visit | Group | Mean | Standard Deviation |
|---|---|---|---|
| **1** | Converted | 29.36 | 0.93 |
| | Demented | 25.33 | 3.32 |
| | Non-Demented | 29.19 | 0.85 |
| **2** | Converted | 28.0 | 2.09 |
| | Demented | 24.25 | 4.4 |
| | Non-Demented | 29.11 | 0.96 |

*Table 3.6 - Cognitive Performance (MMSE) by Group and Visit*

| Visit | Gender (M/F) | Mean | Standard Deviation |
|---|---|---|---|
| **1** | F | 28.1 | 2.59 |
| | M | 26.79 | 3.3 |
| **2** | F | 27.31 | 3.41 |
| | M | 26.42 | 4.3 |

*Table 3.7 - Cognitive Performance (MMSE) by Gender and Visit*

## 4. Mixed Effects Analysis of Variance (ANOVA)

The hypothesis formulated for the research questions specified earlier in this report are as follows:

**Hypothesis for Research Question 1:**

- ***Null Hypothesis (H0):*** There is no significant difference in MMSE scores among different groups (Nondemented vs. Demented) across visits.
- ***Alternative Hypothesis (H1):*** There is a significant difference in MMSE scores among different groups across visits.

**Hypothesis for Research Question 2:**

- ***Null Hypothesis (H0):*** There is no significant difference in MMSE scores between males and females across visits.
- ***Alternative Hypothesis (H1):*** There is a significant difference in MMSE scores between males and females across visits.

A two way mixed effect ANOVA model was built to test the hypotheses for both research questions. Table 4.1 presents the output produced for the first research question to test if the group variable has a significant effect on the cognitive performance (MMSE) across the different visits. The group variable (between-subjects factor) has a significant effect on MMSE scores, with a very small p-value of less than 0.001 ($p < 0.001$), indicating statistical significance. The effect size of 0.445 is considered large, meaning that approximately 44.5% of the variance in MMSE scores can be attributed to the group variable. Furthermore, the visit variable (within-subjects factor) also has a significant effect on the MMSE scores as indicated by a p-value of 0.003 ($p < 0.001$). The small effect size of 0.060 suggests that approximately 6% of the variance in MMSE scores can be attributed to the visit variable. Finally the interaction effect between group and visit is also statistically significant, with a p-value of 0.037 ($p < 0.01$). The small effect size of 0.046 indicates that only approximately 4.6% of the variance in MMSE scores can be attributed to the interaction term between the two variables; group and visit. Hence, with the support of these computed statistics, we reject the null hypothesis as there is sufficient information that there is a significant difference in MMSE scores among different groups across visits.

An interaction plot, figure 4.2, was generated to further understand and look into the interaction term. There appears to be an intersection of lines of the non-demented and converted group. While the non-demented group remains constant (above 29) across both visits, the converted group has a high MMSE score which significantly decreases in the second visit. The demented group has the lowest scores across both visits. These findings and conclusions were confirmed with the output plot as shown in figure 4.3.

| Source | SS | DF1 | DF2 | MS | F | P-Unc | np2 |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Group** | 1328.421 | 2 | 140 | 664.211 | 56.212 | 0.00 | 0.445 |
| **Visit** | 22.378 | 1 | 140 | 22.378 | 8.859 | 0.003 | 0.60 |
| **Interaction** | 17 | 2 | 140 | 8.500 | 3.365 | 0.37 | 0.46 |

*Table 4.1 - Two-Way Mixed Effects ANOVA for Research Question 1*

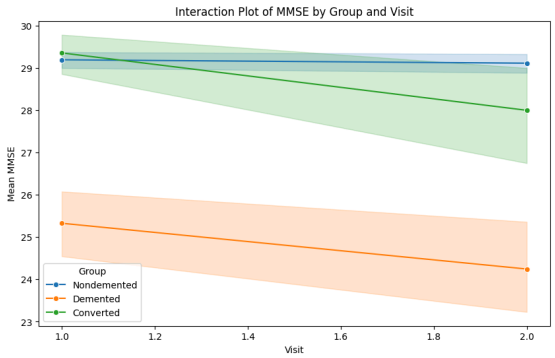


*Figure 4.2 - Interaction Plot of MMSE by Group and Visit (Research Question 1)*

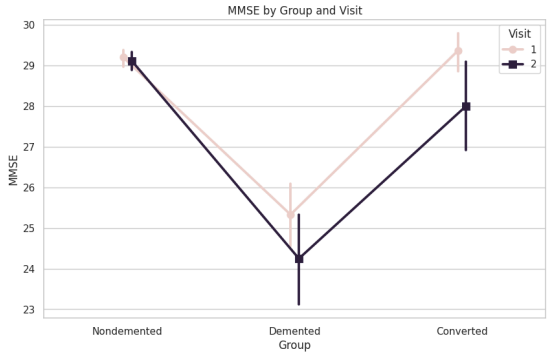


*Figure 4.3 - Output Plot of MMSE by Group and Visit (Research Question 1)*

Table 4.4 summarizes the output from the two-way mixed effects ANOVA for the second research question regarding the difference in cognitive performance (MMSE) between males and females across different visits. The Gender variable (between-subjects factor) has a statistically significant effect on the MMSE scores as indicated by the p-value of 0.039 ($p < 0.05$), suggesting a difference in the scores between males and females. A small effect size of 0.030 means that approximately only 3% of the variance in MMSE scores can be attributed to gender. The visit variable (within-subjects factor) has a statistically significant effect on MMSE scores with a p-value of 0.004 suggesting that there are differences in MMSE scores across different visits ($p < 0.05$). The effect size of 0.058 indicates a small effect size, meaning that approximately 6% of the variance in MMSE scores can be attributed to the visit. Finally, there is no statistically significant interaction between the gender and visit variables with a p-value 0.207 ($p > 0.05$) suggesting that the relationship between the two variables does not significantly impact MMSE scores. Based on these computations, we reject the null hypothesis for the main effects of gender and visit as their p-values are less than 0.05, but we fail to reject the null hypothesis for the interaction effect between gender and vist as its p-value is greater than 0.05.

The output plot for this model as shown in figure 4.5 summarises these conclusions of the main effects on MMSE in a visual format. Both genders had a higher score in the first visit than the second visit, but females had a higher score in both visits than males. Malpetti et al. (2017) stated males demonstrate more protracted age-related decline of brain metabolism than females which explains the differences in MMSE scores between genders.

| Source | SS | DF1 | DF2 | MS | F | P-Unc | np2 |
|---|---|---|---|---|---|---|---|
| **Gender (M/F)** | 88.689 | 1 | 141 | 88.689 | 4.321 | 0.039 | 0.030 |
| **Visit** | 22.378 | 1 | 141 | 22.378 | 8.610 | 0.004 | 0.058 |
| **Interaction** | 4.173 | 1 | 141 | 4.173 | 1.606 | 0.207 | 0.011 |

*Table 4.4 - Two-Way Mixed Effects ANOVA for Research Question 2*

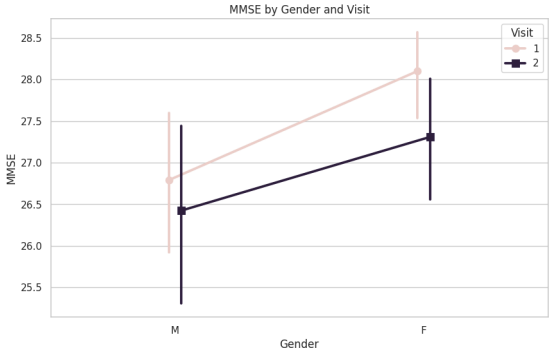


*Figure 4.5 - Output Plot of MMSE by Gender and Visit (Research Question 2)*

## 5. Assumption Checking

Furthermore, the models' diagnostics were checked to see if the mixed effects ANOVA assumptions were satisfied. The first assumption, normality of residuals was checked through the use of shapiro-wilk test. Both models produced a p-value of 0.00 ($p < 0.001$) indicating the violations this assumption - figure 5.1 and 5.2. The second assumption, homogeneity of variances was checked using Levene's and Bartlett's tests. Like the first assumption, the results indicate the violations of this assumption with a p-value of NaN as shown in table 5.3 and 5.4.

| Visit | W | P-value | Normal |
|---|---|---|---|
| 1 | 0.79 | 0.0 | False |
| 2 | 0.76 | 0.0 | False |

*Table 5.1 - Normality of Residual Assumption for Model 1 (Research Question 1)*

| Gender | W | P-value | Normal |
|---|---|---|---|
| M | 0.82 | 0.0 | False |
| F | 0.74 | 0.0 | False |

*Table 5.2 - Normality of Residual Assumption for Model 2 (Research Question 2)*

| | W / T | P-value | Equal Variance |
|---|---|---|---|
| Levene | NaN | NaN | False |
| Bartlett | NaN | NaN | False |

*Table 5.3 - Homogeneity of Variances Assumption for Model 1 (Research Question 1)*

| | W / T | P-value | Equal Variance |
|---|---|---|---|
| Levene | NaN | NaN | False |
| Bartlett | NaN | NaN | False |

*Table 5.4 - Homogeneity of Variances Assumption for Model 2 (Research Question 2)*

## 6. Power Analysis

A power analysis was conducted to determine the appropriate sample size to achieve a desired power level of 0.91, given an effect size of 0.7 and an alpha level of 0.05. The computed sample size was 46 (45.45073088568012). The dataset provided for this assignment exceeds this amount hence adding additional robustness to the statistical analyses performed. The power curve in figure 6.1 presents these results in a graphical format. Additionally, different effect sizes were considered and their appropriate sample sizes were plotted, as shown in figure 6.2.

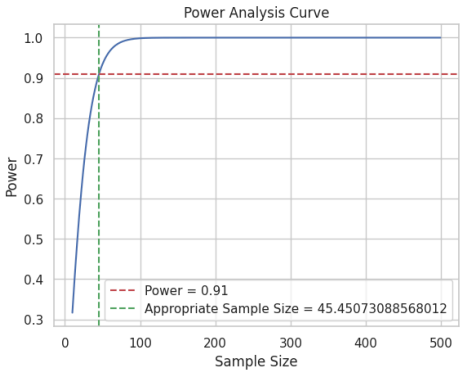


*Figure 6.1 - Power Curve for 0.91 Desired Power and 0.70 Effect Size*

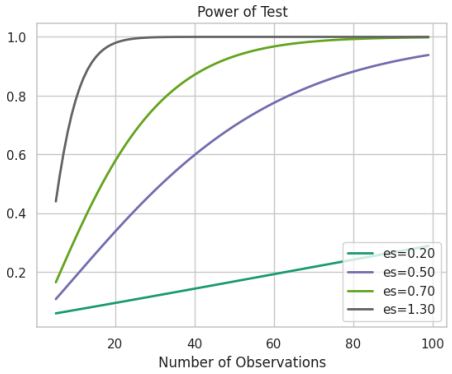


*Figure 6.2 - Power Curve for Various Effect Sizes*

## 7. Limitations

Some limitations of this research include the unequal sample sizes across the groups. Secondly, the dataset's scope may not capture all relevant factors influencing cognitive performance. Furthermore, external and/or confounding variables that are not accounted for in the analysis may influence the MMSE scores. Finally, the violations of the assumptions of normality and homogeneity of variance in the data could potentially impact the results. Despite these limitations, the study provides valuable insights into the relationship between group classification, visit frequency, and MMSE scores.

## 8. Future Works

Some future research directions could include the incorporation of machine learning techniques to predict cognitive decline based on demographic and clinical variables. In addition, the investigation of impact of interventions or treatmnets on cognitive outcomes over time using balanced sample sizes. Moreover, the collaboration with healthcare providers to collect comprehensive data on subjects' cognitive health and outcomes over an extended period can offer deeper insights into the progression of of cognitive decline and the efficacy of interventions. Furthermore, longitudinal studies with diverse populations and settings can help generalize findings and tailor interventions for specific groups. Overall, integrating multidisciplinary approaches and leveraging advanced technologies can advance our understanding and management of cognitive health across populations.

## 9. References

Malpetti, M., Ballarini, T., Presotto, L., Garibotto, V., Tettamanti, M., & Perani, D. (2017, May 31). Gender differences in healthy aging and Alzheimer's Dementia: A 18F‐FDG‐PET study of brain and cognitive reserve. *Human Brain Mapping*, *38*(8), 4212–4227. https://doi.org/10.1002/hbm.23659

Jo, K., Jhoo, J. H., Mun, Y. J., Kim, Y. M., Kim, S. K., Kim, S., Lee, S. H., & Jang, J. W. (2018). The Effect of Cognitive Intervention on Cognitive Improvement in Patients with Dementia. *Dementia and Neurocognitive Disorders*, *17*(1), 23. https://doi.org/10.12779/dnd.2018.17.1.23

Azad, N. A., Al Bugami, M., & Loy-English, I. (2007, June). Gender differences in dementia risk factors. *Gender Medicine*, *4*(2), 120–129. https://doi.org/10.1016/s1550-8579(07)80026-x

Shiroky, J. S., Schipper, H. M., Bergman, H., & Chertkow, H. (2007, October). Can You Have Dementia With an MMSE Score of 30? *American Journal of Alzheimer's Disease & Other Dementiasr*, *22*(5), 406–415. https://doi.org/10.1177/1533317507304744